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CLINICAL REVIEW

Role of surgery in adult obstructive sleep apnoea

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SUMMARY

A surgical approach to treatment of obstructive sleep apnoea (OSA) remains an area of intense debate, both within and without the surgical community itself. Continuous positive airway pressure (CPAP) therapy remains the gold standard for the treatment of OSA, however surgery may be indicated to facilitate CPAP and/or improve compliance in cases where CPAP is poorly tolerated.

This article summarises the current range of surgical treatment options together with the evidence base for their intervention in otolaryngology, maxillofacial and bariatric surgery. The continued evolution of technology has brought new surgical techniques to the fore and it seems likely their utilisation together with a multi-level surgical approach to the airway will continue to influence forthcoming research in OSA. Patient selection and precise evaluation will remain crucial in ensuring that when surgery is indicated, the correct procedure or procedures are performed at the correct anatomical level.

Introduction

Sleep related breathing disorder (SRBD) is used to describe a broad clinical spectrum of recurring partial or complete occlusion of the upper airway. This ranges from snoring to severe obstructive sleep apnoea (OSA). Population based studies demonstrate OSA syndrome affecting approximately 4% of males and 2% females, a level of prevalence comparable to Type I Diabetes [1]. The morbidity and mortality related to OSA is well recognised as an independent risk factor for hypertension, cardiovascular, and cerebrovascular diseases [2]. In addition neurobehavioral morbidities of daytime sleepiness and impaired cognitive function may contribute to motor vehicle and job-related accidents [3,4]. Overall, OSA significantly increases the risk of stroke or death from any cause and in a community based sample moderate-to-severe sleep apnoea is independently associated with a large increased risk of all-cause mortality [5]. The obesity epidemic means problems faced by health professionals in relation to OSA is only likely to increase in the immediate future.

The selection of surgical treatments in OSA remains an area of intense debate, both within and without the surgical community itself. Fundamentally continuous positive airway pressure (CPAP) therapy remains the gold standard for the treatment of OSA, however surgery may be indicated to improve compliance and outcome in cases where CPAP is poorly tolerated. Other non-surgical measures that warrant consideration with demonstrated efficacy include use of oral appliances [6] and sleep position training [7]. Increasing recognition of the multi-level nature of anatomical obstruction means consequentially there exists a large variety of differing surgical techniques used by different surgical specialties in an attempt to combat this problem. In many countries the financial implications of surgical private practice has perhaps contributed to a degree of cynicism as to the range of available surgical procedures for OSA [8] (Table 1).

In this article we summarise the current range of surgical treatments together with the evidence base for their intervention. As such we explore measures enlisted not only by otolaryngologists but maxillofacial and bariatric surgical colleagues. The key aspect of surgery in OSA is selecting the right operation to tackle the individual's specific problem at the correct time. There is a clear distinction that needs to be made with respect to surgery indicated for simple snoring and surgery indicated for OSA.

OSA research: difficulties for the clinician

It is well recognised that there is a paucity of high quality randomised controlled trials for surgical interventions in OSA but it may additionally be highlighted that this is problem faced by

Abbreviations: BMI, body mass index; CPAP, continuous positive airway pressure; CT, computed tomography; MRI, magnetic resonance imaging; OSA, obstructive sleep apnoea; SIGN, Scottish intercollegiate guidelines network (develops evidence based guidelines for the NHS in Scotland); SRBD, sleep related breathing disorder; TMJ, temporomandibular joint.

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Table 1
Range of surgical techniques for obstructive sleep apnoea in adults.

Surgical site	Examples of surgical techniques available	Advantages	Potential difficulties
Nasal	Septoplasty	*Adjunct for better tolerance of CPAP and lower pressures*	*Septal perforation can adversely affect future CPAP use.*
	Septorhinoplasty Turbinate reduction	*Improve nasal airway*	
	Endoscopic sinus surgery		*Requires expert assessment of nasal symptoms/ examination to identify pathology*
Oropharyngeal surgery	Tonsillectomy Uvulopalatopharyngoplasty Laser assisted uvulopalatoplasty	*Prevent retropalatal restriction* *Combined with other procedures in multi-level approach*	*Pain* *May affect future CPAP tolerance*
	Radiofrequency thermotherapy (Soft palate)		*Absence of long-term data in OSA.*
Hypopharyngeal surgery	Radiofrequency thermotherapy (tongue base) Hyoid suspension	*Combined with other procedures in multilevel approach* *Directly deals with anatomical abnormality*	*Absence of long-term data in OSA.*
	Midline glossectomy Epiglottic wedge resection		*Morbidity associated includes dysphagia, odynophagia, dysphonia and aspiration.* *Robotic approach is resource intensive and restricted to specialised centres* *May require 'covering' tracheostomy in post-op period*
Maxillofacial	Maxillomandibular advancement	*Highly effective*	*Highly Invasive* *Need for prolonged fluid diet* *Velopharyngeal incompetence*
Tracheal	Tracheostomy	*Bypasses obstructive segment* *Highly efficient*	*Invasive* *Technically difficult to perform in obese individuals*
Bariatric surgery	Roux-en-Y gastric bypass	*Objective improvement demonstrated-decrease CPAP requirements*	*Maintenance in weight loss required for benefits*
	Vertical banded gastroplasty	*Further health benefits*	*May not be deemed 'curative'*

surgery in general [9]. A recent systematic review indicates the heterogenous end-points used failing to provide any consistency of effect from laser-assisted uvulopalatoplasty or radiofrequency ablation on daytime sleepiness, apnoea reduction, quality of life or snoring [10]. Additionally defining successful treatment is also increasingly difficult given the degree of variance in terminology of success and range of outcome measures used. The research focus should be patient-centric with recognition that although objective, the apnoea–hypopnoea index (AHI) represents a surrogate outcome measure of treatment and we would caution the belief that it is the ultimate arbiter of success [11].

There is much discrepancy within the literature related to defining 'success' of surgical intervention in OSA. Currently, a commonly accepted definition for surgical success is respiratory disturbance index or apnoea–hypopnoea index less than 20 with a reduction greater than 50% and few desaturations less than 90% with improvement of subjective symptoms [12]. Patient-relevant end points are to control the symptoms of OSA and minimise the risk of premature death rather than an arbitrary laboratory derived figure of AHI and this should naturally be taken into consideration on review. A study in 2010 demonstrates the potential benefit in the continuous nature of non-optimal surgical therapy overnight as opposed to a partial use of CPAP [13]. Mathematical modelling demonstrates that the use of CPAP compliance rates appears somewhat arbitrary and in fact disguises insufficient reductions in AHI.

Any coordinated attempts at strengthening the evidence base is naturally to be welcomed and has been recommended in a recent Cochrane review [14]. Work is ongoing in this area highlighting potential trial designs with the requisite clinical equipoise and relevance to influence clinical practice in the treatment of OSA [15].

Intrinsic appeal of surgery for OSA

In the UK, clear Scottish intercollegiate guidelines network (SIGN) guidelines have been provided with a clear focus on primary non-surgical management for OSA given the interpreted poor current evidence base for intervention [16]. However success through CPAP, oral appliances or sleep position training is dependent on patient compliance [6,17]. It is important for clinicians to recognise the difficulties patients face with an appliance-based approach to OSA. Unfortunately, adherence rates are poor with estimates that between 40 and 60% of patients use CPAP as prescribed, many reject therapy within the first few months of their intended treatment [18]. For many patients the long term, daily burden of such devices leads them to seek an alternative in the form of surgery. It is by this nature that surgical techniques become an acceptable avenue for this subgroup of patients. Indeed a survival benefit of surgical intervention as opposed to CPAP has been demonstrated in a population of U.S veteran soldiers with a high likelihood of poor adherence [19].

Assessment of OSA: a surgical perspective

Clinical assessment begins with observations of any obvious morphological features such as retrognathia or dental mal-occlusion,

neck collar size and body mass index (BMI). Evaluation of the upper airway will assist in identifying any obstructive anatomical abnormalities contributing to turbulent airflow and is a vital precursor to any successful surgical procedure [20].

Anterior rhinoscopy using a simple nasal speculum allows visualisation of the anterior aspect of the nasal cavity and helps in identifying problems of caudal dislocation of the septum and nasal valve compromise.

Flexible endoscopic examination allows comprehensive evaluation of the nasal passage and will identify pathology such as deviated nasal septum, nasal polyps and rhinosinusitis. This is important as they may be the underlying cause of failed compliance and efficacy in patients being treated with nasal CPAP. The oro and hypopharynx should also be assessed to provide the clinician with useful information as to contributing pathology and anatomical influence. It is important to consider the size of palatine tonsils, the length of the soft palate and uvula and presence of redundant pharyngeal folds. Friedman tongue position [21] and Mallampati grading [22] are utilised by many clinicians in order to select patients suitable for palatal surgery.

A meta-analysis has demonstrated the diagnostic value of the Friedman tongue position and Mallampati grading to predicting severity of OSA [23]. Pooled data of 2513 patients demonstrated a significant correlation in both assessment tools that was not found to be significantly affected by publication bias when assessed using Egger's regression.

One must however recognise that as this assessment is performed during wakefulness it may not truly reflect what happens to the upper airway during sleep. There will likely be variation in the muscle tone in the state of wakefulness and different stages of sleep.

A commonly used technique during the flexible endoscopic assessment is Muller's manoeuvre. This demonstrates collapse of various segments of the pharynx and allows comparison of the obstruction caused by each segment. The patient could also be asked to simulate a snoring sound to try and ascertain the level responsible for causing turbulent airflow.

Investigation of OSA

In order to comprehensively establish if the patient is suffering from OSA or not, it is vital to arrange either a full hospital based polysomnography or an ambulatory home sleep study [24]. In order to localise the potential site of obstruction compromising the upper airway, numerous techniques have been described but none are entirely satisfactory. These include CT and MRI imaging, acoustic analysis, pressure transducer measurements and sleep nasendoscopy [25].

Sleep nasendoscopy (SNE) otherwise known as drug induced sedation endoscopy (DISE) allows a three dimensional visualisation of the upper airway during sleep [26]. This assessment is carried out in an operating theatre setting with an anaesthetist providing sedation and close monitoring of cardiovascular and respiratory parameters. Sedative agents commonly used are midazolam or propofol or in a combination of both.

Drug induced sleep is different from natural physiological sleep and would have a tendency to exacerbate muscle relaxation; but one could argue that the drug used for sedation has the same effect on the different segments of the pharynx thus it would allow us to compare the proportionate obstruction caused at each anatomical level in a similar manner that may exist in natural sleep.

The authors experience is that when performed by individuals adequately trained in both the technique and its interpretation it forms a useful adjunct to surgical decision-making. An audit of 2485 procedures performed over 10 y has demonstrated that SNE correlates well with apnoea–hypopnoea index and mean oxygen desaturation [27]. Similarly, SNE has allowed site-specific target selection in surgical patients and improved OSA surgical outcomes in patients undergoing laser assisted palatoplasty with or without tonsillectomy [28].

Surgical management of OSA

An appropriate surgical philosophy would dictate that patients should not come to any harm and careful patient selection would ensure a better surgical outcome. An unrelenting enthusiasm for surgical intervention in OSA patients may certainly be criticised and instead the decision should be made with a team-based approach to assessment. It should be acknowledged that for certain individuals (e.g., those with a high BMI and multiple medical co-morbidities) surgery would not be in the patient's best interests. Additionally complications of surgical intervention can prevent efficient future use of CPAP and communication of this is an important part of the consent process particularly important in intended radical palatal surgery. In many cases however, modern reconstructive airway surgery can be an important adjunct to improve CPAP compliance and long-term effectiveness.

Nasal surgery

Patients may present to the rhinologist for surgical intervention not for curative purposes but for adjunctive treatment to improve the efficacy of nasal continuous positive airway pressure (CPAP) [29]. Surgical procedures performed for SRBD includes septoplasty, septorhinoplasty, functional endoscopic sinus surgery, turbinate reduction and nasal valve surgery.

Quality of life assessment in OSA patients with nasal obstruction has been assessed. Surgically correcting an obstructed nasal airway significantly improved disease specific and generic quality of life measurements thus substantiating the role of nasal surgery in treating this patient group. Despite the significant improvement noted in quality of life parameters, in common with other cohort and randomised studies there was no statistically significant improvement in the objective polysomnographic data [30].

Pharyngeal morphology could have an impact on the outcome of nasal surgery in patients with obstructive sleep apnoea and nasal obstruction. The pharyngeal morphological features reviewed included tonsil size, Mallampati score, narrowness of fauces and retroglossal dimension. Morinaga et al. concluded that a favourable nasal surgical outcome in this group of patients was seen in individuals with a high positioned soft palate or in those with a wide retroglossal space [31].

More than 50% of CPAP users complain of significant nasal symptoms, including nasal congestion, rhinorrhoea, dryness and sneezing [32]. As such it is vital that patients who do not comply with or adhere poorly to CPAP therapy should undergo detailed evaluation of their upper airway to identify obstructive pathology that may be surgically correctable. This may lead to a reduction in the CPAP pressure and therefore improve overall compliance. A group of CPAP patients undergoing radiofrequency turbinate reduction reported a subjective improvement in nasal obstruction that was linked to improved CPAP use [33]. Similarly, reduction of pressure requirement for CPAP therapy was noted in patients with mild, moderate and severe OSA following nasal surgery.

Tonsillectomy and radical palatal surgery

Tonsillectomy is a potential first line surgical treatment of OSA where oropharyngeal anatomy is compromised. In several case

Fig. 1. Friedman tongue position IV.

series, patients with mild, moderate and severe OSA with grade III or IV tonsils demonstrate a reduction in post-operative AHI by over 50% through tonsillectomy alone [34,35].

Palatal surgery remains prominent in the otolaryngologists' surgical armamentarium for OSA. The more radical procedure of palatal resection is usually required when the minimally invasive approach has failed or in patients with more severe symptoms or in some selected patients where treatment with nasal CPAP therapy has failed.

Uvulopalatopharyngoplasty (UPPP) was first performed in 1964 [36] but subsequently many variations of the technique have been reported with resurgence influenced by Fujita in the 1980's [37]. The general principle of this procedure is to enlarge the retropalatal dimension yet the overall success rate from mild-severe OSA is reported to be approximately 40% [38]

Interestingly in patients with Friedman tongue position IV, where only the hard palate is visible on mouth opening (Fig. 1) palatal surgery is unlikely to be successful. In contrast, Friedman tongue position I (Fig. 2) where visualisation of the entire uvula and tonsils is possible, an 80.6% success rate following uvulopalatopharyngoplasty at six months post procedure [39].

Browaldh et al. [40] recently produced a well-designed prospective single-centre randomised controlled trial in moderate to severe OSA patients assessing outcome after UPPP at six months in comparison to a control group. Stratification and subgroup analysis by body mass index and indeed Friedman tongue position additionally supported the dramatic overall results showing a clinically relevant reduction in AHI of 60% in the UPPP arm in comparison to 11% in the control group.

Radical UPPP is generally a painful procedure associated with morbidity and unfortunately mortality has also been reported. Complications such as nasopharyngeal stenosis and incompetence

Fig. 2. Friedman tongue position I.

create concern. There have also been problems in patients being unable to tolerate CPAP therapy after radical UPPP. For these reasons, conservative modifications of the technique have been described including utilisation of laser and modified Z-palatoplasty [41].

Laser assisted palatoplasty

The laser was first introduced in the 1980's as a high energy tool with improved surgical precision and was used in laser assisted uvulopalatoplasty (LAUP) under local anaesthesia. Kamami described a technique using CO_2 laser delivered via a specially designed hand-piece with a back stop to prevent inadvertent laser injury to the posterior pharyngeal wall [42].

Kamami's original description recommended this office-based procedure performed under local anaesthesia to be repeated at about six weekly intervals until optimum benefit was attained. In our institution, it is performed in a single stage procedure under a general anaesthetic taking up to 25% of the soft palate length and 50% of the uvular length with simultaneous excision of the redundant posterior pillars [43]

Complications are fairly minimal and usually short-lived, with globus sensation an occasional outcome. Although there is little change in contour, care should be taken in the patients selected for this procedure in particular with those who are professional singers, actors and some foreign language speakers.

Laser assisted palatoplasty for OSA has been encouraging in both short and long term outcomes. A telephone survey of patients and partners showed 69% reported subjective symptom improvement at nine months and 55% reported improvement at the time of interview with a median follow-up time of 59 mo [44]. This may be improved through use of sleep nasendoscopy in patient selection to target the specific anatomically involved site as used in this case [45]. In a select group of failed CPAP patients, it is demonstrated that palatal surgery may be appropriate as an alternative or aid in improving CPAP compliance by improving oropharyngeal dimensions [46].

All series report some deterioration with time however with reported success rates in OSA from 30% to 70% [47]. Data interpretation has become somewhat difficult with great variation in the definition of agreed endpoints. Meta-analysis conducted by Verse and Pirsig confirmed the difficulty encountered as differing criteria of surgical success were used in different studies [48].

The UPPP and the above mentioned modifications of the procedure improve the retropalatal dimensions but all involve some resection of the soft palate tissue. In contrast, transpalatal advancement pharyngoplasty involves excision of the hard palate and a palatal advancement flap but without excision of the soft palate. The end result is to pull the palate forward and superiorly and is likened to what happens after maxillary advancement. With this technique scar tissue formation and velopharyngeal insufficiency is less prominent when compared to UPPP. Outcome data on this particular technique remains currently limited however [49].

Palatal surgery alone may not be sufficient in resolving the symptoms of OSA and other treatment modalities may need to be used in combination. This may include appliances such as mandibular advancement devices, CPAP or indeed other surgical techniques addressing the nose or the tongue given the typical multi-level obstruction that is often encountered in many of these patients.

Minimally invasive palatal surgery and tongue base surgery

Minimally invasive palatal surgery under local anaesthesia may be conducted through injecting chemicals into the soft palate resulting in scarring and stiffening. This technique of "injection

snoreplasty" utilises chemicals such as sodium tetradecyl sulphate to stiffen the soft palate [50]. This technique is not recommended in patients with OSA and even in simple snorers the results are not entirely satisfactory although some short-term benefits have been reported. Complications of palatal ulceration and fistula formation have been reported but these were thought to have completely resolved and only caused temporary problem. The Pillar® procedure has also been used to insert palatal implants within the soft palate to increase its stiffness and thus minimise obstruction. There remains a lack of long-term follow up as well as objective evidence for OSA patients [51].

The use of radiofrequency thermotherapy has been reported to be beneficial in some cases of simple snorers and mild OSA when used in the soft palate and tongue base. Monopolar, bipolar and plasma mediated ablation devices (Somnus®, Celon® and Coblation®) are available. The treatment can quite easily be carried out under local anaesthesia or in combination with other surgeries under general anaesthesia e.g., resection of redundant tonsillar pillars or elongated uvula.

Radiofrequency energy is used interstitially to create thermal trauma with subsequent fibrosis leading to stiffening and some shrinkage of the soft palate and tongue base [52]. The interstitial energy delivery with the bipolar devices avoids mucosal damage and ulceration. Scanning electron microscopy has shown at cellular level the impact of thermal trauma comparing CO_2 laser with cutting radiofrequency. With cutting radiofrequency the epithelium is intact, whereas with the CO_2 laser there is shedding of the squamous epithelium.

The complications encountered with radiofrequency treatment to the soft palate and tongue base are usually mild and include mucosal ulceration; however mucosal breakdown and abscess/fistula formation has been reported.

It is quite likely that in patients who relapse, multiple treatment applications would be required as there may be some regeneration of elastic fibres following earlier fibrosis.

As a recent meta-analysis demonstrates although long-term data is limited, the studies performed to date are encouraging with the results of radiofrequency thermotherapy being maintained for up to 24 mo [53]. The opportunity to combine this with other interventions remains a key area of research and clinical interest [54].

A transcervical surgical technique to access the retro-lingual space and perform radiofrequency ablation of the lingual tonsils in OSA has recently been described [55] A combination of Doppler ultrasound and fluoroscopy is utilised in order to allow the introduction and progression of a stylet into the lingual tonsils whilst avoiding trauma to the hypoglossal nerves and lingual arteries. The surgery is undertaken with a combination of sedation and local anaesthesia. This approach awaits further formal studies to confirm both the safety and efficacy of this technique but demonstrates the ever-evolving new approaches to treat areas of airway collapse.

Hypopharyngeal surgery for OSA

The involvement of the tongue base and epiglottis in snoring and OSA is usually under estimated and in many cases where palatal surgery has failed to achieve a successful outcome it may be due to the fact that identifying the contribution of the tongue or the epiglottis to the upper airway obstruction has been missed.

SNE is particularly useful in identifying exactly the nature of hypopharyngeal collapse in that in some cases it is just the case of a large tongue retracting posteriorly and pushing the epiglottis with it (Fig. 3). In other cases there may be a dual problem with epiglottic retraction like a "trap-door" on to the larynx in addition to tongue base retraction (Fig. 4). In these cases the surgical

Fig. 3. Tongue retraction pushing epiglottis to occlude larynx.

treatment requires addressing the epiglottis as well as the tongue-base. The technique was first described by Chabolle detailing a method of tongue base reduction and with hyoid epiglottoplasty [56].

Depending on the nature of obstruction, the surgery required may involve midline glossectomy or in cases of epiglottic "trap-door" phenomenon, epiglottic wedge resection [57]. The consent process naturally requires detailed discussion of potential morbidity as many potential complications particularly in relation to tongue base surgery may be deemed unacceptable for a subgroup of patients. Dysphagia, odynophagia, dysphonia and aspiration may occur and early involvement of the speech and language therapist can be helpful in the post-operative period.

A case series evaluation of 'open' midline glossectomy in fifty patients demonstrated a demonstrable improvement in post-operative AHI scores in approximately 56% of patients. Interestingly this surgical outcome was found to be directly related to Friedman tongue position with 'position III' having a 75.9% success rate in comparison to 'position IV' where the rate drops to 28.6% [58].

The use of a more limited technique of 'submucosal linguoplasty' in combination with palatal surgery for treatment of OSA has been subject to a case series outcome analysis in twenty-seven

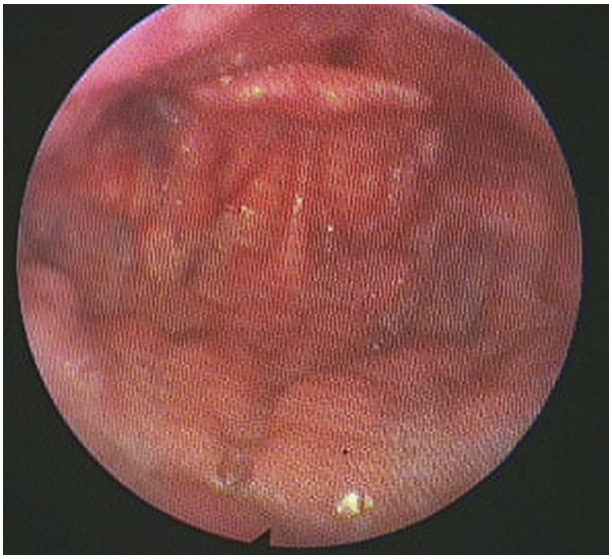

Fig. 4. Epiglottic 'Trapdoor' phenomenon.

patients [59]. Prospectively collected from a single-surgeon series the results are suggestive that this mucosal sparing technique is clinically effective in a range of symptom and polysomnographic outcomes with a high rate of patient acceptance. Speech (47%), swallow (33%) and taste (33%) were affected at six month follow up yet the patients themselves described their any residual impairment as 'mild' with a mean visual analogue scale of two out of 10 or less.

Transoral robotic surgery for OSA

A recent development in the surgical management of OSA is the use of da Vinci robot allowing transoral robotic surgery (TORS). This is being utilised for patients with severe OSA who have failed CPAP treatment and persistent hypopharyngeal obstruction following experiences in tongue base malignancy [60].

A minimally invasive telerobotic system allows excellent 3D visualisation, immaculate precision and absence of tremor. This improved access allows oropharangeal enlargement anteriorly through tongue base reduction and treatment of inward inspiratory collapse of a floppy epiglottis, aryetenoids and aryepiglottic folds. Vicini et al. [61] present their preliminary outcome data at three years demonstrating a polysomnogram success rate (post-op apnoea hypopnoea index <15) of approximately 80%. No emergency post-operative interventions were required and good functional results in pain, swallowing and quality of life were displayed.

The surgery was however supplemented with multiple other procedures in the case series including septoplasty, UPPP, supraglottoplasty, turbinate reduction, and ethmoidectomy. Similarly another case series [62] presents favourable outcomes using a transoral robotic technique in combination with palatal surgery. The potential confounding factors of these additional procedures present us with a difficulty in interpretation of these results yet additionally place further value on the evolving concept of multi-level surgery when the outcomes are reviewed [63]. The peri-operative management for these patients varies between centres but increasing experience in the technique and knowledge of the potential complications has led to a drive away from a prophylactic or 'covering' tracheostomy as standard part of the patient pathway.

Lin et al. [64] demonstrate the use of a TORS technique in isolation for tongue base obstruction excluding patients who received additional forms of upper airway alteration. This case series is small with only 12 patients yet a statistically significant reduction in AHI is demonstrated from this preliminary data.

A robotic surgical approach to hypopharangeal obstruction is likely to be applicable to a small subset of patients with severe obstructive sleep apnoea. Present case series analysis suggests for adequately selected individuals a robotic approach may yet prove an appropriate treatment modality within specialist centres with the requisite equipment and experience.

Multi-level surgery of the upper airway

The benefits and efficacy of multi-level surgery of the upper airway in OSA is shown through mostly level IV evidence yet a recent meta-analysis is suggestive of patient benefit [54]. This included 1978 patients with multi-level sleep apnoea surgery involving at least two involved anatomic sites: nose, oropharynx and hypopharynx, gave a success rate of 66.4%. In this case a reduction of AHI less than 20 and a greater than 50% reduction was used to define success.

It is this area that perhaps promises the most for the future, recognising a multi-level obstruction requires a surgical approach at multiple levels akin to that provided non-surgically through CPAP. A combination of surgical techniques are enlisted in order to best serve the individual patient following a thorough diagnostic assessment of their underlying anatomy. A recent large multicentre cohort study combined a modified uvulopalatopharyngoplasty with Coblation channelling of the tongue for mild, moderate and severe OSA. This demonstrated a clinically relevant reduction in AHI at three months post-operatively with no documented complications [65].

The safety and complication rate of multi-level surgery in obstructive sleep apnoea has been evaluated further in a large retrospective review [66]. The outcomes of 487 consecutive patients with OSA were evaluated. This population received a total of 1698 procedures involving combinations of nasal, palate and tongue base surgery. An overall complication rate of 7.1% was described including post-operative oxygen desaturation, persistent hypertension and secondary haemorrhage. Only one patient required re-intubation secondary to upper airway obstruction.

Unfortunately without a coherent diagnostic and outcome focused treatment pathway, multi-level airway surgery can appear merely an exercise in surgical capability and technological versatility. A recent Australian study showed forty-one different combinations of surgery on ninety-four individuals for OSA. Importantly this degree of procedural variability between surgeons prevents isolation of outcome measures through research and is itself subject to criticism [67].

Ultimately, greater procedural standardisation is required in order to truly evaluate patient outcomes and it is in this area that research and resources should be focused.

Hyoid suspension

This may be utilised in order to prevent hypopharyngeal collapse of the tongue during sleep. This technique is currently most often performed as part of multi-level surgery for patients with OSA and some centres advocate its use in this manner [68]. Its use in isolation however gives a published success rate of less than 13% while dysphagia and speech difficulties in the post-operative period are acknowledged within the literature [69].

Hypoglossal nerve stimulation [70]

Experimental research in both humans and animals has demonstrated an increase in pharyngeal neuromuscular activity during sleep in obstructive sleep apnoea patients but at an insufficient level to overcome airway collapse. As such there has been a focus on selective stimulation of upper airway dilator muscles (e.g., genioglossus) to improve airway patency without arousing patients from sleep. An implantable neurostimulator to synchronise hypoglossal nerve stimulation with inspiration has shown early promise in a single arm feasibility study [70,71]. Twenty-one patients were recruited with moderate to severe OSA who had failed to tolerate CPAP. A significant decrease in OSA symptomology and in-laboratory polysomnography was established at six months post-implantation. Two device-related 'serious' adverse events occurred in this cohort necessitating removal or replacement. The authors recognise the long term safety and efficacy of this treatment warrants further clinical evaluation but it remains a treatment modality with high expectations for future benefit given the technological advances in this area.

Maxillomandibular advancement

Maxillomandibular advancement (MMA) may be viewed as the most successful surgical procedure after tracheotomy for OSA yet

the conventional wisdom is that its perceived invasive nature has an associated morbidity that precludes its routine use.

As such it is classically considered in relation to adult craniofacial deformities where it offers expansion of the airway and associated soft tissue distraction at multiple levels with positive long term follow up result. A recent systematic review and meta-analysis [72] shows MMA as highly effective at treating OSA. The mean AHI decreased from 63.9/h to 9.5/h ($p < 0.001$) with a pooled surgical success rate of 86.0%. Overall, 43.2% of subjects were cured with an AHI <5/h and an increased cure rate (66.7%) for those with a preoperative AHI <30/h. The low major and minor complication rates of 1.0% and 3.1% suggest that this intervention should be considered for the appropriate patient cohort. Patients do however require a soft diet for approximately two months following surgery while complications of TMJ dysfunction and velopharyngeal incompetence are also cited.

Rapid maxillary expansion is an orthodontic treatment for maxillary constriction that increases maxillary width and reduces nasal resistance but with a low morbidity profile. The technique is most commonly recognised within the paediatric population yet a pilot study involving young adults with mild or moderate OSA demonstrated an overall significant reduction in AHI [73].

Tracheostomy

This was the first effective treatment for patients with severe obstructive sleep apnoea and remains an efficient if dramatic means of bypassing the upper airway [74]. In adults, it may be used as a short-term measure to protect the upper airway following an invasive upper airway procedure or a permanent option to relieve OSA. It is often seen as a last resort and is often not a technically easy procedure to perform due to the association of OSA with morbid obesity. It does however reduce the morbidity and mortality rates in this patient group. For a cohort of patients this procedure dramatically improves quality of life and is well tolerated when compared to the burden of living with severe OSA [75].

Bariatric surgery

Obesity represents a leading risk factor for OSA. As such in a certain subgroup of morbidly obese patients weight loss may be associated with a resolution of sleep apnoea, in which the upper airway critical pressure falls below −4 cm H_2O [76]. Reduction in weight frequently does not cure OSA in itself and there often remains a persistence of mild degree of OSA in these patients. Unfortunately, only a select few patients with sleep related breathing disorders succeed in maintaining their dietary-achieved weight reduction. Achieving this through laparoscopic means via the vertical banded gastroplasty and Roux-en-Y gastric bypass may provide a surgical treatment of this disorder as well as the myriad of other health benefits.

Various retrospective cohort studies in bariatric surgery show potential benefit in the treatment of OSA yet may not be termed 'curative' [77]. A key focus is required on meaningful long-term weight loss maintenance following surgery.

A cohort study from Florida reports significant objective improvement in obesity related OSA in patients following bariatric surgery when assessed at a median of 11 mo after the intervention [78]. In 101 patients of whom 50% were classed as severe preoperatively, the mean respiratory distress index fell from 51 ± 4 to 15 ± 2 with a decrease in both CPAP use and the pressure settings required. Lower CPAP pressures may yet be found to improve overall compliance with CPAP. However currently little long-term outcome data exists to clearly demarcate how much of a reduction in the AHI or CPAP pressures is required to result in meaningful increases in CPAP tolerance and increased patient compliance.

A recent randomised control trial demonstrated weight loss in obese patients with moderate or severe OSA through bariatric surgery (laparoscopic adjustable gastric banding) did not translate into a statistically significant reduction in AHI at two years in comparison to a conventional weight loss programme [79]. As such cessation of CPAP or other therapies for OSA following bariatric surgery should not occur on assumption without formal laboratory based evaluation.

Practice points

1) Limitations of current literature are: most studies retrospective case series analysis. Many studies single centre (or surgeon). Adverse events not always included. Few well designed, randomised controlled trials. Almost no cost effectiveness analysis.
2) The 'holy grail' in the surgical treatment of sleep apnoea is seeking an intervention with long-term benefits and low surgical morbidity.
3) Careful patient selection remains critical in ensuring the best results and the surgery should be tailored to the specific pathology encountered.
4) To dismiss surgical treatment of OSA would appear to fail to recognise our developing understanding of multi-level airway surgery and the compliance issues that can leave CPAP unused.
5) Working in partnership rather than in competition with inter-professional colleagues offers the best approach to advance the care offered to patients suffering with OSA.
6) The continued evolution of technology has brought new surgical techniques to the fore and it seems likely their utilisation together with a multi-level surgical approach to the airway will continue to influence forthcoming developments in OSA.

Research agenda

1) Focus on assessment of long-term surgical outcomes with comparative effectiveness studies.
2) Establish collaborative, multi-centre randomised controlled studies in order to best prepare patients for surgical intervention.
3) Meticulous recording of adverse events.
4) Enhance patient selection to predict responders to surgery- move away from 'one size fits all approach'.

References

[1] Lee W, Nagubadi S, Kryger MH, Mokhlesi B. Epidemiology of obstructive sleep apnea: a population-based perspective. Expert Rev Respir Med 2008;2:349–64.
[2] Marshall NS, Wong KKH, Liu PY, Cullen SRJ, Knuiman MW, Grunstein RR. Sleep apnea as an independent risk factor for all-cause mortality: the Busselton Health Study. Sleep 2008;31:1079–85.
[3] George CF, Nickerson PW, Hanly PJ, Miller TW, Kryger MH. Sleep apnoea patients have more automobile accidents. Lancet 1987;2:447.

* The most important references are denoted by an asterisk.

[4] Young T, Peppard PE, Gottlieb DJ. Epidemiology of obstructive sleep apnea: a population health perspective. Am J Respir Crit Care Med 2002;165:1217–39.

[5] Yaggi HK, Concato J, Kernan WN, Lichtman JH, Brass LM, Mohsenin V. Obstructive sleep apnoea as a risk factor for stroke and death. N Engl J Med 2005;353:2034–41.

[6] Ferguson KA, Cartwright R, Rogers R, Schmidt-Nowarra M. Oral appliances for snoring and obstructive sleep apnea: a review. Sleep 2006;29:244–62.

[7] Permut I, Diaz-Abad M, Chatila W, Crocetti J, Gaughan JP, D'Alonzo GE, et al. Comparison of positional therapy to CPAP in patients with positional obstructive sleep apnea. J Clin Sleep Med 2010;6:238–43.

[8] Elshaug AG, Moss JR, Hiller JE, Maddern GJ. Upper airway surgery should not be the first line treatment for obstructive sleep apnoea in adults. BMJ 2008;336:44–5.

[9] Franklin KA, Anttila H, Axelsson S, Gislason T, Maasilta P, Myhre KI, et al. Effects and side-effects of surgery for snoring and obstructive sleep apnea – a systematic review. Sleep 2009;32:27–36.

[10] Elshaug AG, Moss JR, Southcott A, Hiller JE. Redefining success in airway surgery for obstructive sleep apnea: a meta analysis and synthesis of the evidence. Sleep 2007;30:461–7.

[11] Weaver EM, Woodson BT, Steward DL. Polysomnography indexes are discordant with quality of life, symptoms, and reaction times in sleep apnea patients. Otolaryngol Head Neck Surg 2005;132:255–62.

[12] Lye KW, Deatherage JR. Surgical procedures for the treatment of obstructive sleep apnea. Semin Orthod 2009;15:94–8.

[13] Ravesloot MJL, de Vries N. Reliable calculation of the efficacy of non-surgical and surgical treatment of obstructive sleep apnoea revisited. Sleep 2011;34:105–10.

*[14] Sundaram S, Lim J, Lasserson TJ. Surgery for obstructive sleep apnoea in adults. Cochrane Database Syst Rev; 2005:CD001004.

*[15] Field CJ, Robinson S, Mackay S, Harrison JD, Marshall NS. Clinical equipoise in sleep surgery: investigating clinical trial targets. Otolaryngol Head Neck Surg 2011;145:347–53.

[16] Scottish Intercollegiate Guidelines Network. Management of obstructive sleep apnoea/hypopnoea syndrome in adults: a national clinical guideline. Edinburgh: SIGN; 2003.

*[17] Powell N. Upper airway surgery does have a major role in the treatment of obstructive sleep apnea: "the tail of the dog." J Clin Sleep Med 2005;1:236–40.

*[18] Weaver TE, Grunstein RR. Adherence to continuous positive airway pressure therapy: the challenge to effective treatment. Proc Am Thorac Soc 2008;5:173–8.

[19] Weaver EM, Maynard C, Yueh B. Survival of veterans with sleep apnea: continuous positive airway pressure versus surgery. Otolaryngol Head Neck Surg 2004;130:659–65.

[20] Kotecha B. The nose, snoring and obstructive sleep apnoea. Rhinology 2011;49:259–64.

[21] Friedman M, Ibrahim H, Bass L. Clinical staging for sleep-disordered breathing. Otolaryngol Head Neck Surg 2002;127:13–21.

[22] Mallampati SR, Gatt SP, Gugino LD, Desai SP, Waraksa B, Freiberger D, et al. A clinical sign to predict difficult tracheal intubation: a prospective study. Can Anaesth Soc J 1985;32:429–34.

[23] Friedman M, Hamilton C, Samuelson CG, Lundgren ME, Pott T. Diagnostic value of the Friedman tongue position and Mallampati classification for obstructive sleep apnea: a meta-analysis. Otolaryngol Head Neck Surg 2013;148:540–7.

[24] Overland B, Skatvedt O, Kvaerner KJ, Akre H. Pulse oximetry: sufficient to diagnose severe obstructive sleep apnoea. Sleep Med 2002;3:133–8.

*[25] Georgalas C, Garas G, Hadjihannas E, Oostra A. Assessment of obstruction level and selection of patients for obstructive sleep apnoea surgery: an evidence-based approach. J Laryngol Otol 2010;124:1–9.

[26] Croft C, Pringle M. Sleep nasendoscopy: a technique of assessment in snoring and obstructive sleep apnoea. Clin Otolaryngol 1991;16:504–9.

[27] Kotecha BT, Hannan AS, Khalil HMB, Georgalas C, Bailey P. Sleep nasendoscopy: a 10-year retrospective audit study. Eur Arch Otorhinolaryngol 2007;264:1361–7.

[28] Chisholm E, Kotecha B. Oropharyngeal surgery for obstructive sleep apnoea in CPAP failures. Eur Arch Otorhinolaryngol 2007;264:1361–7.

[29] Li HY, Lee LA, Wang PC, Chen NH, Lin Y, Fang TJ. Nasal surgery for snoring in patients with obstructive sleep apnoea. Laryngoscope 2008;118:354–9.

[30] Verse T, Maurer JT, Pirsig W. Effect of nasal surgery on sleep-related breathing disorders. Laryngoscope 2002;112:64–8.

[31] Morinaga M, Nakata S, Yasuma F, Noda A, Yagi H, Tagaya M, et al. Pharyngeal morphology: a determinant of successful nasal surgery for sleep apnoea. Laryngoscope 2009;119:1011–6.

[32] Hoffstein V, Viner S, Mateika S, Conway J. Treatment of obstructive sleep apnea with nasal continuous positive airway pressure. Am Rev Respir Dis 1992;145:841–5.

[33] Powell N. Radiofrequency treatment of turbinate hypertrophy in subjects using CPAP: a randomized double-blind, placebo-controlled trial. Laryngoscope 2001;111:1783–90.

[34] Verse T, Kroker BA, Pirsig W, Brosch S. Tonsillectomy as a treatment of obstructive sleep apnea in adults with tonsillar hypertrophy. Laryngoscope 2000;110:1556–9.

[35] Tan L, Tan A, Hsu P, Loh I, Yuen H, Chan Y, et al. Effects of tonsillectomy on sleep study parameters in adult patients with obstructive sleep apnea-a prospective study. Sleep Breath; 2013. http://dx.doi.org/10.1007/s11325-013-0875-7 [epub ahead of print].

[36] Ikematsu T. Study of snoring. 4th report. Therapy. J Jpn Otol Rhinol Laryngol Soc 1964;64:434–5 [in Japanese].

[37] Fujita S, Conway W, Zorick F. Surgical correction of anatomic abnormalities in obstructive sleep apnoea syndrome: uvulopalatopharyngoplasty. Otolaryngol Head Neck Surg 1981;89:923–34.

[38] Sher AE, Schechtman KB, Piccirillo JF. The efficacy of surgical modifications of the upper airway in adults with obstructive sleep apnea syndrome. Sleep 1996;19:156–77.

[39] Friedman M, Ibrahim H, Joseph NJ. Staging of obstructive sleep apnea/hypopnea syndrome: a guide to appropriate treatment. Laryngoscope 2004;114:454–9.

[40] Browaldh N, Nerfeldt P, Lysdahl M, Bring J, Friberg D. SKUP3 randomised controlled trial: polysomnographic results after uvulopalatopharyngoplasty in selected patients with obstructive sleep apnoea. Thorax 2013;68:846–53.

[41] Friedman M, Kelley K. Modification of Z-palatoplasty technique and review of five-year experience. Oper Techn Otolaryngol 2012;23:30–5.

[42] Kamami YV. Outpatient treatment of snoring with CO_2 laser, LAUP: laser assisted UPPP. J Otolaryngol 1994;23:391–4.

[43] Kotecha B, Paun S, Leong P, Croft C. Laser assisted uvulopalatoplasty: an objective evaluation of the technique and results. Clin Otolaryngol 1998;23:354–9.

*[44] Iyngkaran T, Kanaglingam J, Rajeswaran R, Georgalas C, Kotecha B. Long-term outcomes of laser-assisted uvulopalatoplasty in 168 patients with snoring. J Laryngol Otol 2006;120:932–8.

[45] Patel N, Gill J, Kotecha B. How I do it – the Kotecha technique for laser palatoplasty. Eur Arch Otorhinolaryngol 2006;263:152–5.

[46] Walker RP, Garrity T, Gopalsami C. Early polysomnographic findings and long-term subjective results in sleep apnoea patients treated with laser assisted uvulopalatoplasty. Laryngoscope 1999;109:1438–41.

[47] Mickelson SA, Ajuba A. Short-term objective and long-term subjective results of laser-assisted uvulopalatoplasty for obstructive sleep apnoea. Laryngoscope 1999;109:362–7.

[48] Verse T, Pirsig W. Laser-assisted uvulopalatoplasty: a meta-analysis. In: Fabiani M, Saponara M, editors. Surgery for snoring and obstructive sleep apnoea syndrome. 1st ed. The Hague: Kugler Publications; 2003. pp. 463–74.

[49] Woodson BT, Robinson S, Lim HJ. Trans palatal advancement pharyngoplasty outcomes compared with uvulopalatopharygoplasty. Otolaryngol Head Neck Surg 2005;133:211–7.

[50] Brietzke SE, Mair EA. Injection snoreplasty: how to treat snoring without all the pain and expense. Otolaryngol Head Neck Surg 2001;124:503–10.

[51] Ho WK, Wei WI, Chung KF. Managing disturbing snoring with palatal implants; a pilot study. Arch Otolaryngol Head Neck Surg 2004;130:753–8.

[52] Stimpson P, Kotecha B. Histopathological and ultrastructural effects of cutting radiofrequency energy on palatal soft tissues: a prospective study. Eur Arch Otorhinolaryngol 2011;268:1829–36.

[53] Farrar J, Ryan J, Oliver E, Gillespie MB. Radiofrequency ablation for the treatment of obstructive sleep apnea: a meta-analysis. Laryngoscope 2008;118:1878–83.

*[54] Lin HC, Friedman M, Chang HW, Gurpinar B. The efficacy of multi-level surgery of the upper airway with obstructive sleep apnoea/hypopnea syndrome. Laryngoscope 2008;118:902–8.

[55] Blumen M, Coquile F, Chabolle L. Lingual tonsil reduction in OSA: transcervical radiofrequency ablation. Eur Ann Otorhinolaryngol Head Neck Dis 2012;129:339–42.

[56] Chabolle F, Wagner I, Blumen MB, Séquert C, Fleury B, De Dieuleveult T. Tongue base reduction with hyoepiglottoplasty: a treatment for severe obstructive sleep apnoea. Laryngoscope 1999;109:1273–80.

[57] Woodson BT, Fujita S. Laser midline glossectomy and lingualplasty for obstructive sleep apnoea. In: Fairbanks DNF, Fujita S, editors. Snoring and obstructive sleep apnoea. 2nd ed. New York, NY: Raven Press; 1994. pp. 189–94.

[58] Suh GD. Evaluation of open midline glossectomy in the multilevel surgical management of obstructive sleep apnea syndrome. Otolaryngol Head Neck Surg 2013;148:166–71.

[59] Gunawardena I, Robinson S, MacKay S, Woods CM, Choo J, Esterman A, et al. Submucosal lingualplasty for adult obstructive sleep apnoea. Otolaryngol Head Neck Surg 2013;148:157–65.

[60] Vicini C, Dallan I, Canzi P, Frassineti S, La Pietra MG, Montevecchi F. Transoral robotic tongue base resection in obstructive sleep apnoea hypopnoea syndrome: a preliminary report. ORL J Otorhinolaryngol Relat Spec 2010;72:22–7.

*[61] Vicini C, Dallan I, Canzi P, Frassineti S, Nacci A, Seccia V, et al. Transoral robotic surgery of the tongue base in obstructive sleep apnea-hypopnea syndrome: anatomic considerations and clinical experience. Head Neck 2012;34:15–22.

[62] Friedman M, Hamilton C, Samuelson CG, Kelley K, Taylor D, Pearson-Chauhan, et al. Transoral robotic glossectomy for the treatment of obstructive sleep apnoea-hypopnea syndrome. Otolaryngol Head Neck Surg 2012;46:854–62.

[63] Vicini C, Montevecchi F, Pang K, Bahgat A, Dallan I, Frassineti S, et al. Combined transoral robotic tongue base surgery and palate surgery in obstructive sleep apnea-hypopnea syndrome: expansion sphincter pharangoplasty versus uvulopalatopharangoplasty. Head Neck 2014;36:77–83.

[64] Lin HS, Rowley JA, Badr MS, Folbe AJ, Yoo GH, Victor L, et al. Transoral robotic surgery for treatment of obstructive sleep apnoea-hypopnea syndrome. Laryngoscope 2013;123:1811–6.
[65] MacKay SG, Carney AS, Woods C, Antic N, McEvoy RD, Chia M, et al. Modified uvulopalatopharyngoplasty and coblation channeling of the tongue for obstructive sleep apnea: a multi-centre Australian trial. J Clin Sleep Med 2013;9:117–24.
*[66] Pang KP, Siow JK, Tseng P. Safety of multilevel surgery in obstructive sleep apnea: a review of 487 cases. Arch Otolaryngol Head Neck Surg 2012;138:353–7.
[67] Elshaug AG, Moss JR, Southcott AM, Hiller JE. An analysis of the evidence-practice continuum: is surgery for obstructive sleep apnoea contra-indicated? J Eval Clin Pract 2007;13:3–9.
[68] Hormann K, Baisch A. Hyoid suspension in rhinologic and sleep apnoea surgical techniques. In: Kountakis SE, Onerci M, editors. Rhinologic and sleep apnoea surgical techniques. 1st ed. Heidelberg: Springer; 2007. pp. 355–60.
[69] Bowden MT, Kezirian EJ, Utley D, Goode RL. Outcomes of hyoid suspension for the treatment of obstructive sleep apnea. Arch Otolaryngol Head Neck Surg 2005;131:440–5.
[70] Kezirian EJ, Boudewyns A, Eisele DW, Schwartz AR, Smith PL, Van de Heyning PH, et al. Electrical stimulation of the hypoglossal nerve in the treatment of obstructive sleep apnea. Sleep Med Rev 2010;14:299–305.
[71] Eastwood PR, Barnes M, Walsh JH, Maddison KJ, Hee G, Schwartz AR, et al. Treating obstructive sleep apnea with hypoglossal nerve stimulation. Sleep 2011;34:1479–86.
*[72] Holty JEC, Guilleminault C. Maxillomandibular advancement for the treatment of obstructive sleep apnea: a systematic review and meta-analysis. Sleep Med Rev 2010;14:287–97.
[73] Cistulli PA, Palmisano RG, Poole MD. Treatment of obstructive sleep apnea syndrome by rapid maxillary expansion. Sleep 1998;21:831–5.
[74] Hormann K, Verse T. Surgery for sleep disordered breathing. Heidelberg: Springer; 2005. pp. 21–70.
[75] Thatcher GW, Maisel RH. The long-term evaluation of tracheostomy in the management of severe obstructive sleep apnea. Laryngoscope 2003;113:201–4.
[76] Cowan DC, Ivingston E. Obstructive sleep apnoea syndrome and weight loss: review. Sleep Disord 2012;1:1.
[77] Lettieri CJ, Eliasson AH, Greenburg DL. Persistence of obstructive sleep apnea after surgical weight loss. J Clin Sleep Med 2008;4:333–8.
*[78] Haines KL, Nelson LG, Gonzalez R, Torella T, Martin T, Kandil A, et al. Objective evidence that bariatric surgery improves obesity-related obstructive sleep apnea. Surgery 2007;141:354–8.
[79] Dixon JB, Schachter LM, O'Brien PE, Grima M, Brown W, Bailey M, et al. Surgical vs conventional therapy for weight loss treatment of obstructive sleep apnea a randomized controlled trial. J Am Med Assoc 2012;308:1142–9.